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The Effect of Temperature and Humidity on Viability of Stored Seeds in Hawaii

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Hawaii Agricultural Experiment Station
Bulletin No. 90
1943

HAWAII AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF HAWAII

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Ernest K. Akamine

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INTRODUCTION

Because the prevailing temperatures and relative humidities of the atmosphere in Hawaii are relatively high, many crop seeds in ordinary storage deteriorate rapidly. By ordinary storage is meant the storage of packaged seeds on shelves and counters of stores and homes, or the storage of bagged seeds in warehouses. Under such conditions the seeds are continuously subjected to the prevailing high temperatures and high relative humidities of the surrounding air.

It is the purpose of this bulletin to present the results of experiments designed to develop practical methods of prolonging the viability of stored seeds. The experiments extended over a period of approximately 6 years, during which seeds were stored under various temperature and humidity conditions in Honolulu. Seeds selected for the experiments included garden, field, and forage crops that are common in Hawaii.

Crocker (6) gives an excellent review of the literature on seed viability. As to the record longevity of seeds, the best known authentic case is the one of the seed of Japanese or East Indian lotus (*Nelumbo nucifera*) which was said to have germinated readily after being buried in soil in Manchuria between 120 and 400 years (13). Fantastic claims of longevity of thousands of years for wheat grains mummified in Egyptian tombs (21) and for other seeds buried under heaps of old mining and smelting debris in Greece (22, 23) have

[1] Project was initiated in the Agronomy Division and later transferred to the Plant Physiology Division.

been disproved. Darlington (7) has shown that some seeds buried in soil in bottles were still viable after 60 years. Because of favorable environmental conditions, some farm seeds have been stored under ordinary conditions for many years without loss of vitality (25, 4, 14, 18).

The effect of temperature and relative humidity on viability of stored vegetable seeds has been studied by Spencer (16), Barton (2), and Boswell, *et al.* (3). Steinbauer and Steinbauer (17), Isaac (11), and Moss (12) determined the optimum temperature and relative humidity conditions for storage of tree seeds.

EXPERIMENTS

This study consisted of two parts. First, the effect of various relative humidities on the maintenance of seed viability was studied at room temperature. Second, the effects of various low temperatures and low relative humidities were studied.

Effect of Various Relative Humidities at Room Temperature

Freshly harvested seeds well-cured at room temperature were used for the experiment. Seeds of Nanking soybean, Kentucky Wonder garden bean (pole), Guam field corn, Hairy Peruvian alfalfa, Station Accession No. 1801 lettuce, Taichu rice (with hull), and the grass *Pennisetum ciliare* were stored in large desiccators at room temperature (71° to 80° F.) under relative humidities maintained with solutions of sulphuric acid of various strengths. The strength of the acid required to produce the required humidities was determined by the procedure worked out by Wilson (24) and used by Dillman (8). The relative humidities selected were approximately 15, 30, 45, 60, 75, and 90 percent. In addition, seeds were stored in an airtight chamber without solution, and seeds were also stored in the open in the laboratory. The seeds were stored on October 2, 1935, at which time the initial germination and moisture content of the seeds were determined.

After storage, germination tests were conducted at intervals, once in approximately 2 months at the beginning and once in approximately 6 months toward the latter part. Duplicate samples of 50 seeds each were used. Soybean, garden-bean, corn, alfalfa, and rice seeds were germinated in the Minnesota electric germinator (dark interior) maintained at a temperature of 86° F. The lettuce seed was germinated in petri dishes exposed to light at room temperature.[2] Seed of the grass *Pennisetum ciliare* was germinated in soil in the greenhouse.[3]

The criterion of germination was the emergence of the primary root for those seeds germinated in the germinator and in the petri dish. The emergence of the shoot above the surface of the soil was taken as the criterion of germina-

[2] The seed of this variety of lettuce, like the seed of some other varieties, is light-sensitive, that is, it requires light for germination in the laboratory (15, 10, 20).

[3] The seed of *Pennisetum ciliare* germinates in soil, but not in the germinator nor in a petri dish. The anomaly is caused by the presence of an inhibitor which diffuses from the seed hull and accumulates locally in the germinator and in the petri dish but which is readily adsorbed by soil particles and powdered charcoal (1).

tion for the seed[4] of the grass planted in soil. The germination period for the seeds in the germinator and petri dish was approximately 1 week, and for the grass seed in the soil it was between 2 and 3 weeks. Seeds of alfalfa which were ungerminated after 1 week were scarified by making a small cut in the seedcoat and regerminated.

At the time the germination tests were made, the specific gravity of the sulphuric-acid solutions was determined with a hydrometer, and the divergence from the required specific gravity was corrected by the addition of water or concentrated sulphuric acid to the solution.

The results of the periodic germination tests conducted on the seeds stored under various relative humidities at room temperature are recorded in tables 1 and 2.

According to tables 1 and 2, there is a general similarity among the species in their reaction toward different storage conditions, yet, specifically, each has certain characteristic differences. As far as tolerance to different storage conditions is concerned, alfalfa seed is the most tolerant, producing the highest germination in favorable as well as in unfavorable storage conditions. After 6¼ years of storage in the low relative humidities of 15, 30, and 45 percent, alfalfa seed germinated more than 90 percent.[5] For the storage of soybean and lettuce seeds, the lower the humidity the better is the maintenance of viability. Soybean seed stored in 15 percent relative humidity still germinated 33 percent on the last test, whereas those subjected to the other storage conditions either had long since died or were very near death when the last test was conducted. Lettuce seed germinated more than 80 percent in the lowest humidity after more than six years of storage. Optimum storage condition for garden bean is in relative humidities of 30 and 45 percent. Humidities of 15, 30, and 45 percent are the best storage atmospheres for corn and rice. The seed of *Pennisetum ciliare* maintained its germination after several years of storage under the three lowest humidities.

In figure 1 are represented graphically the germination behaviors of alfalfa seed in storage under various conditions of humidity at room temperature. This seed represents one of the long-lived species under ordinary storage conditions. The germination behaviors of rice seed, which is one of the short-lived species, are presented in figure 2. In order to present the trend of the germination more readily, the curves for these graphs were drawn from points obtained by the use of "running averages" of the data in tables 1 and 2.

If figure 1 is superimposed over figure 2, the contrast between the germination behaviors of the two species is clearly shown. In the first place, the rice seed lost its viability in ordinary storage much faster than the alfalfa seed. In the second place, although the alfalfa seed stored under the 15, 30, and 45 percent humidities maintained its original germination after several years of

[4] The "seed" of this grass is really a fascicle composed of 2 to 3 or more spikelets clumped together and bearing from none to three caryopses or grains. On the average, 100 fascicles contained 96 caryopses, and the germination percentage was figured on this basis for the grass seed.

[5] A very good negative correlation ($r = -.979 \pm .019$) existed between the percentage of hard-coated seeds and the relative humidity of storage, and a good positive correlation ($r = +.879 \pm .102$) existed between the percentage of hard-coated seeds and the percentage of germination. Thus in alfalfa, maintenance of viability is determined to a large extent by the percentage of hard seeds present, which in turn is determined by the humidity of the storage medium at room temperature.

Table 1. Effect of various relative humidities on maintenance of seed viability in storage at room temperature (71° to 80° F.)

Storage condition	Seed	Germination percentage on															
		1935		1936					1937		1938		1939	1940		1941	1942
		Oct. 2[1]	Dec. 2	Feb. 2	Apr. 2	June 2	Aug. 2	Oct. 2	Jan. 2	July 2	Jan. 2	July 2	July 2	Jan. 2	July 2	Jan. 2	Jan. 2
15 percent relative humidity	Soybean	100	100	97	98	100	93	80	63	....	69	73	68	75	41	27	33
	Garden bean	92	98	89	92	94	....	96	84	64	74	67	61	14	11	23	0
	Corn	95	93	97	96	98	94	96	96	95	94	93	94	86	97	78	83
	Alfalfa[2]	100	100	98	100	100	100	100	99	97	94	95	98	95	99	95	98
	Lettuce	96	99	97	97	92	89	92	97	87	94	87	88	85	75	83	88
	Rice	91	90	93	90	86	94	93	79	84	88	71	70	67	51	34	18
	Pennisetum[3]	46	56	46	55	....	33	54	....	52	50	39	34	33	30	35	26
30 percent relative humidity	Soybean	100	99	99	97	91	82	82	76	79	80	58	48	27	21	8	4
	Garden bean	92	97	85	94	99	88	91	84	77	85	62	50	28	34	40	20
	Corn	95	98	96	97	96	94	97	95	96	91	94	89	80	83	81	80
	Alfalfa[2]	100	100	100	99	100	100	98	98	99	90	96	96	96	97	97	96
	Lettuce	96	99	98	98	91	94	87	98	97	90	....	84	89	37	56	10
	Rice	91	93	89	87	89	94	95	....	90	88	79	65	54	42	33	6
	Pennisetum[3]	46	40	41	42	....	32	52	....	51	33	46	32	41	47	44	19

Table 1.—continued

Storage condition	Seed	Germination percentage on															
		1935		1936					1937		1938		1939	1940		1941	1942
		Oct. 2[1]	Dec. 2	Feb. 2	Apr. 2	June 2	Aug. 2	Oct. 2	Jan. 2	July 2	Jan. 2	July 2	July 2	Jan. 2	July 2	Jan. 2	Jan. 2
45 percent relative humidity	Soybean	100	100	99	94	94	88	75	78	62	65	41	16	10	5	0	
	Garden bean	92	94	89	96	95	93	76	85	77	80	68	56	29	41	47	31
	Corn	95	97	99	100	96	97	97	98	92	97	94	87	87	88	70	70
	Alfalfa[2]	100	100	99	98	100	100	100	98	100	92	96	97	96	97	91	94
	Lettuce	96	99	99	94	94	95	89	96	95	96	87	51	28	2	0	
	Rice	91	92	92	93	87	89	86	88	85	86	87	72	59	38	28	5
	Pennisetum[3]	46	62	51	51	30	47	46	....	49	56	59	50	39	34	35	29
60 percent relative humidity	Soybean	100	100	100	93	93	89	86	73	75	25	5	0				
	Garden bean	92	97	88	94	96	88	88	74	52	63	29	15	0			
	Corn	95	95	99	95	99	96	98	96	97	95	88	69	55	21	0	
	Alfalfa[2]	100	100	99	99	100	96	97	98	93	83	76	64	66	41	30	12
	Lettuce	96	96	99	95	88	83	93	88	84	75	4	0				
	Rice	91	95	92	87	87	95	83	41	27	0						
	Pennisetum[3]	46	50	40	23	24	28	38	....	35	23	....	6	1	0		

[1] Initial germination at time of storage.
[2] Hard seeds cut.
[3] Germination percentage based on number of sound caryopses in sample (96 caryopses in 100 fascicles).

Table 2. Effect of various relative humidities on maintenance of seed viability in storage at room temperature (71° to 80° F.)

Storage condition	Seed	Germination percentage on														
		1935		1936					1937		1938		1939	1940		1941
		Oct. 2[1]	Dec. 2	Feb. 2	Apr. 2	June 2	Aug. 2	Oct. 2	Jan. 2	July 2	Jan. 2	July 2	July 2	Jan. 2	July 2	Jan. 2
75 percent relative humidity	Soybean	100	100	100	99	97	59	15	1	0						
	Garden bean	92	96	92	88	87	68	29	1	0						
	Corn	95	98	99	97	97	93	87	64	24	0					
	Alfalfa[2]	100	99	99	96	75	46	35	15	9	3	3	0			
	Lettuce	96	99	97	76	34	21	3	2	0						
	Rice	91	92	90	91	66	16	0								
	Pennisetum[3]	46	46	27	41	9	3	0								
90 percent relative humidity	Soybean	100	100	94	21	0										
	Garden bean	92	95	61	0											
	Corn	95	100	67	52	30	6	0								
	Alfalfa[2]	100	99	58	26	13	11	7	5	0						
	Lettuce	96	88	85	0											
	Rice	91	89	73	44	14	1	0								
	Pennisetum[3]	46	48	2	2	1	0									

Table 2.—continued

Storage condition	Seed	Germination percentage on 1935 Oct. 2[1]	1935 Dec. 2	1936 Feb. 2	1936 Apr. 2	1936 June 2	1936 Aug. 2	1936 Oct. 2	1937 Jan. 2	1937 July 2	1938 Jan. 2	1938 July 2	1939 July 2	1940 Jan. 2	1940 July 2	1941 Jan. 2
Airtight	Soybean	100	100	100	98	89	91	77	47	12	0					
	Garden bean	92	99	95	93	96	87	84	56	13	0					
	Corn	95	99	98	96	92	84	61	28	29	0					
	Alfalfa[2]	100	100	100	93	96	95	95	91	95	73	24	17	13	16	0
	Lettuce	96	98	96	90	84	80	77	85	31	3	0				
	Rice	91	90	84	48	13	2	0								
	Pennisetum[3]	46	51	34	43	....	21	17	8	18	0					
Open	Soybean	100	100	100	99	94	87	76	69	3	0					
	Garden bean	92	98	87	91	90	90	86	76	....	3	0				
	Corn	95	95	97	98	99	93	97	94	94	83	62	15	0		
	Alfalfa[2]	100	100	100	92	98	95	97	92	78	49	22	10	18	8	0
	Lettuce	96	97	96	86	88	85	71	91	25	0					
	Rice	91	93	87	88	82	77	44	14	0						
	Pennisetum[3]	46	52	32	45	11	12	....	14	5	0					

[1] Initial germination at time of storage.
[2] Hard seeds cut.
[3] Germination percentage based on number of sound caryopses in sample (96 caryopses in 100 fascicles).

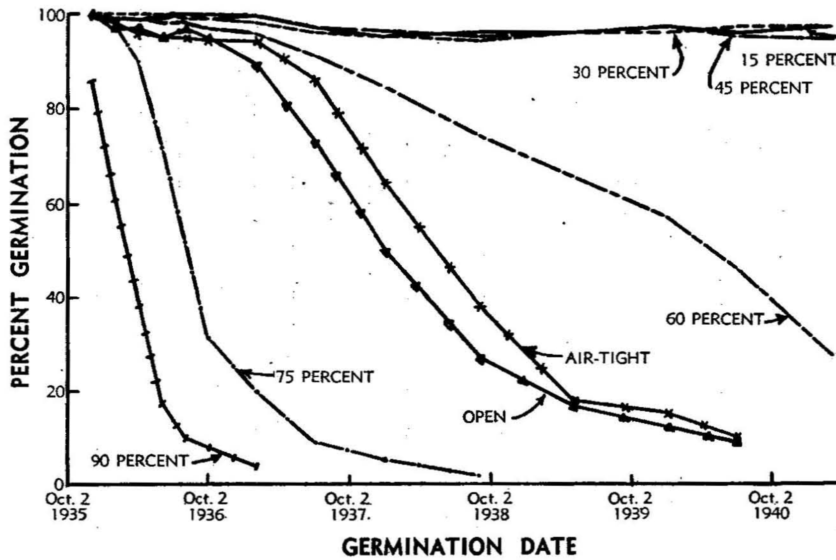

Fig. 1—The effect of relative humidity on the viability of alfalfa seed in storage at room temperature (71° to 80° F.).

storage, the rice seed stored under the same humidities gradually lost its germinative power as the storage period lengthened. In the third place, airtight storage is definitely inferior to open storage in the case of rice seed, but airtight storage may be slightly superior to open storage in the case of alfalfa seed.

Despite these differences, these two species have one thing in common: the trend of behavior of one species to the various storage conditions is very similar to that of the other species (figs. 1 and 2). In both species the 15, 30, and 45 percent humidities are the best storage media, and with each increment increase in the storage humidity beyond 45 percent there is a corresponding increase in the detrimental effect on the longevity of the seeds. Of interest is the position of the open storage curves in figures 1 and 2. They lie about midway between the 60- and 75-percent curves. This position of the open storage curves was expected, since the mean relative humidity of the air was about 68 percent (mean daily range of 64 to 73 percent).

If the germination data of the other stored seeds are plotted, the resulting curves will show the same trend as that shown in figures 1 and 2.

The common local belief that air-dried seeds maintain their viability better in airtight containers than in ordinary storage at room temperature is shown by these experiments to be fallacious. Of the seven species stored, only in the case of alfalfa did airtight storage show any superiority over open storage (tables 1 and 2; figs. 1 and 2), and this was very slight. Airtight storage of corn and rice was definitely inferior to open storage. The other four species did not show any preference to either airtight or open storage. Thus it is seen that storage of air-dried seeds in airtight containers does not prolong the life of the seeds any better than storage in the open, and that in some cases airtight storage is inferior to open storage.

The results of this experiment show that seeds stored at relative humidities lower than that of the air (64 to 73 percent) at room temperature (71° to 80° F.) retain their vitality better than those stored in ordinary storage, and that seeds stored at humidities higher than that of the air lose their vitality very rapidly (figs. 1 and 2).

Moisture determinations made on the seeds when they had completely lost their viability, or at the conclusion of the experiment for those seeds that were still viable, showed that the moisture content of the seeds stored at the high humidities was in general higher than that of the seeds stored at the low humidities. In the case of alfalfa seed, the moisture content at the time of storage was 13.86 percent. After storage at humidities of 15, 30, 45, 60, 75, and 90 percent, the moisture content was 7.20, 9.61, 10.54, 10.52, 13.64, and 16.72 percent, respectively. In the case of soybean seed, the original moisture content was 11.43 percent, and the final moisture content after storage in the airtight chamber and in open storage was 10.94 and 9.79 percent, respectively. After storage at relative humidities of 15, 30, 60, and 75 percent, the moisture content was 7.67, 7.97, 9.72, and 12.88 percent, respectively. Thus it seems that the effect of relative humidity in maintaining viability is associated with the moisture content of the stored seeds.

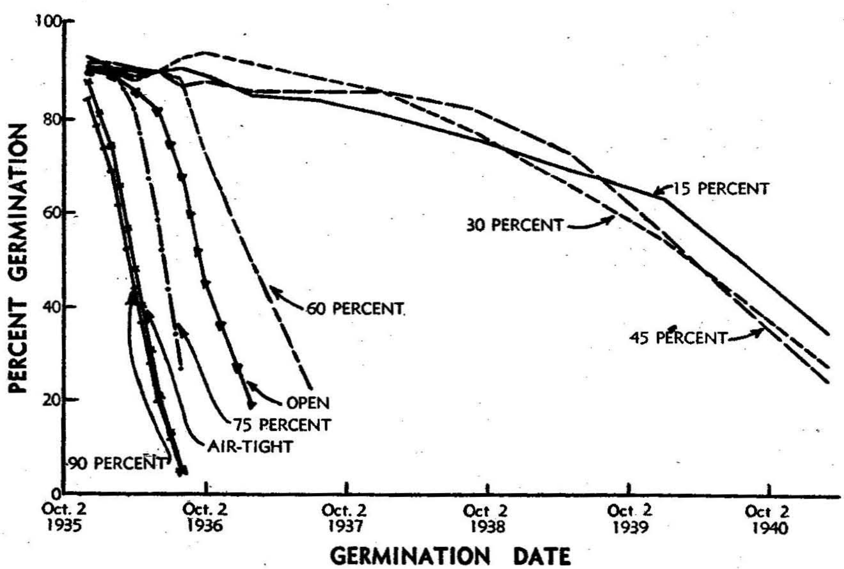

Fig. 2—The effect of relative humidity on the viability of rice seed in storage at room temperature (71° to 80° F.).

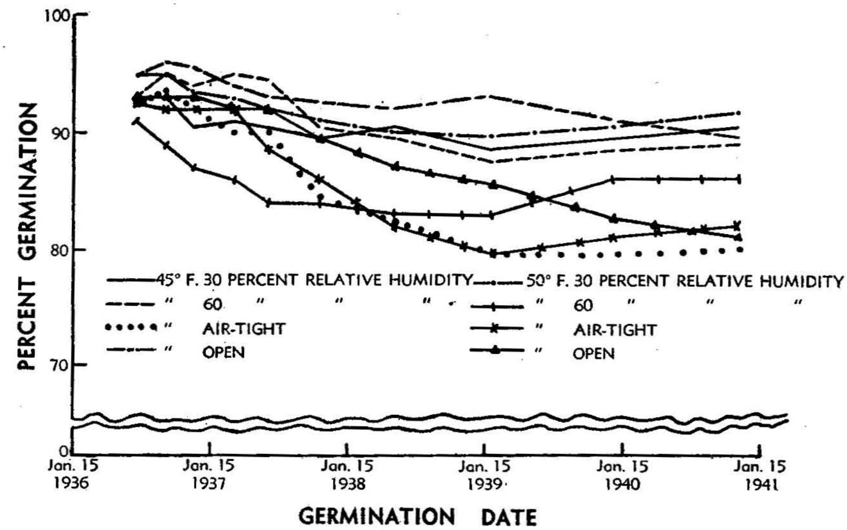

Fig. 3—The effect of low temperature and low relative humidity on the viability of stored lettuce seed.

Effect of Various Low Temperatures and Relative Humidities

On January 15, 1936, freshly harvested seeds of Tokio soybean, Taichu rice, Hairy Peruvian alfalfa, Kentucky Wonder garden bean (pole), and Station Accession No. 1801 lettuce were stored at relative humidities of approximately 30 and 60 percent at low temperatures of approximately 45, 50, 59, and 68° F.[6] The humidity was maintained with solutions of sulphuric acid as in the previous experiment. Some seeds of each species were stored in air-tight containers without a humidity control under each temperature, and control lots of seeds stored open were also included under each temperature. The humidity to which the seeds in the open storage was subjected was probably slightly lower than that of the normal air.

At the time of storage, an initial germination test involving duplicate samples of 50 seeds each was made, and subsequent germination tests were made at intervals of about two months at the beginning and at intervals of about 12 months toward the end of the storage period. All seeds except lettuce seed, which was germinated in petri dishes at room temperature, were germinated in the germinator.

The sulphuric acid solutions were tested when germination tests were made, and any divergence in the strength of the solutions from that required was corrected.

[6] The writer is indebted to Mr. O. C. McBride of the Federal Bureau of Entomology and Plant Quarantine for use of cold storage facilities.

Table 3. Effect of low temperatures and low relative humidities on maintenance of seed viability

Storage condition	Seed	Germination percentage on												
		1936					1937			1938	1939	1940	1941	
		Jan. 15[1]	Mar. 15	May 15	Sept. 15	Nov. 15	Jan. 15	July 15	Oct. 15	Apr. 15	Apr. 15	Apr. 15	Apr. 15	Dec. 15
45° F. 30 percent relative humidity	Soybean	97	95	90	70	64	60	67	65	56	20	25	15	8
	Rice	92	79	84	81	86	88	81	84	83	71	40	50	42
	Alfalfa[2]	87	96	91	98	98	99	95	100	96	....	97	93	94
	Garden bean	95	98	99	90	93	79	97	88	88	93	82	63	61
	Lettuce	92	95	92	93	91	86	94	91	87	....	88	93	90
45° F. 60 percent relative humidity	Soybean	97	90	90	82	71	68	69	....	43	26	22	19	7
	Rice	92	88	88	85	73	77	81	69	65	70	41	33	12
	Alfalfa[2]	87	91	90	99	96	99	95	98	....	95	96	94	89
	Garden bean	95	95	99	94	90	89	85	95	84	89	89	88	87
	Lettuce	92	93	92	95	99	91	94	....	86	89	87	92	89
45° F. airtight	Soybean	97	84	89	87	79	85	85	86	88	36	43	8	0
	Rice	92	84	87	84	73	79	72	58	60	37	15	0	
	Alfalfa[2]	87	97	92	98	99	100	99	99	98	80	94	81	71
	Garden bean	95	97	96	99	90	90	87	94	90	92	87	80	80
	Lettuce	92	96	91	91	96	89	85	....	80	82	76	80	81
45° F. open	Soybean	97	85	92	87	75	79	87	79	78	36	34	9	6
	Rice	92	81	84	87	85	83	77	69	70	53	32	12	2
	Alfalfa[2]	87	85	96	100	99	98	97	99	92	....	96	88	94
	Garden bean	95	98	99	93	91	92	95	91	93	92	86	77	75
	Lettuce	92	95	97	97	94	94	90	93	93	92	93	85	88

[1] Initial germination at time of storage.
[2] Hard seeds cut.

Table 4. Effect of low temperatures and low relative humidities on maintenance of seed viability

Storage condition	Seed	Germination percentage on												
		1936					1937			1938	1939	1940	1941	
		Jan. 15[1]	Mar. 15	May 15	Sept. 15	Nov. 15	Jan. 15	July 15	Oct. 15	Apr. 15	Apr. 15	Apr. 15	Apr. 15	Dec. 15
50° F. 30 percent relative humidity	Soybean	97	93	86	68	....	62	62	73	66	28	9	4	6
	Rice	92	80	84	75	84	83	83	72	76	66	34	39	31
	Alfalfa[2]	87	94	94	98	96	100	97	100	89	....	99	98	97
	Garden bean	95	96	98	96	83	84	95	96	85	96	83	79	83
	Lettuce	92	98	94	95	93	92	92	91	88	89	90	95	92
50° F. 60 percent relative humidity	Soybean	97	84	89	79	....	73	83	83	75	28	36	6	6
	Rice	92	81	80	85	78	79	83	78	76	61	53	39	33
	Alfalfa[2]	87	93	97	98	97	100	98	98	99	....	97	89	91
	Garden bean	95	96	91	97	90	90	92	90	90	93	87	78	76
	Lettuce	92	95	89	88	85	86	84	80	85	82	86	90	86
50° F. airtight	Soybean	97	83	83	76	79	....	86	83	79	20	4	2	0
	Rice	92	72	79	82	75	79	68	64	62	28	5	0	
	Alfalfa[2]	87	94	98	99	97	100	99	96	98	81	95	91	82
	Garden bean	95	100	97	98	96	95	91	96	86	85	86	86	83
	Lettuce	92	95	92	91	91	95	91	77	80	81	80	82	84
50° F. open	Soybean	97	84	90	78	78	85	82	84	76	25	26	21	12
	Rice	92	82	85	82	80	82	81	76	72	62	41	27	20
	Alfalfa[2]	87	90	87	100	92	97	100	97	97	....	98	98	95
	Garden bean	95	96	91	89	81	97	89	92	80	87	81	80	78
	Lettuce	92	94	93	92	94	93	89	92	84	83	83	80	79

[1] Initial germination at time of storage.
[2] Hard seeds cut.

Table 5. Effect of low temperatures and low relative humidities on maintenance of seed viability

Storage condition	Seed	Germination percentage on												
		1936					1937			1938	1939	1940	1941	
		Jan. 15[1]	Mar. 15	May 15	Sept. 15	Nov. 15	Jan. 15	July 15	Oct. 15	Apr. 15	Apr. 15	Apr. 15	Apr. 15	Dec. 15
59° F. 30 percent relative humidity	Soybean	97	74	75	68	42	50	51	56	44	13	14	3	0
	Rice	92	88	78	83	79	70	....	74	68	59	33	32	14
	Alfalfa[2]	87	93	91	100	100	99	96	98	88	....	97	96	94
	Garden bean	95	97	94	96	....	....	90	87	85	91	81	45	48
	Lettuce	92	98	97	89	92	94	98	93	78	83	87	90	88
59° F. 60 percent relative humidity	Soybean	97	79	81	78	64	67	69	67	50	16	4	0	
	Rice	92	85	81	88	82	80	77	72	68	38	18	16	5
	Alfalfa[2]	87	96	97	100	87	97	96	98	87	....	99	93	88
	Garden bean	95	95	99	91	98	84	94	93	97	99	91	85	83
	Lettuce	92	90	93	92	92	90	92	84	....	89	89	43	0
59° F. airtight	Soybean	97	74	86	77	46	40	48	52	37	10	0		
	Rice	92	82	80	78	68	61	34	22	5	13	1	0	
	Alfalfa[2]	87	93	95	98	93	100	96	93	70	72	86	81	90
	Garden bean	95	99	94	91	89	95	93	83	87	79	71	57	62
	Lettuce	92	96	94	94	94	94	88	....	74	46	53	5	0
59° F. open	Soybean	97	....	76	87	58	53	66	68	44	15	1	2	2
	Rice	92	80	81	72	80	88	76	72	53	35	17	18	12
	Alfalfa[2]	87	96	89	100	96	98	99	96	91	....	97	93	97
	Garden bean	95	98	97	99	89	88	91	96	86	93	70	59	62
	Lettuce	92	94	95	85	96	88	94	86	92	86	94	87	84

[1] Initial germination at time of storage.
[2] Hard seeds cut.

Table 6. Effect of low temperatures and low relative humidities on maintenance of seed viability

Storage condition	Seed	Germination percentage on 1936 Jan. 15[1]	1936 Mar. 15	1936 May 15	1936 Sept. 15	1936 Nov. 15	1937 Jan. 15	1937 July 15	1937 Oct. 15	1938 Apr. 15	1939 Apr. 15	1940 Apr. 15	1941 Apr. 15	1941 Dec. 15
68° F. 30 percent relative humidity	Soybean	97	60	73	65	38	30	33	36	15	5	4	0	
	Rice	92	77	71	72	76	77	66	64	40	33	11	5	3
	Alfalfa[2]	87	90	91	98	97	99	98	98	100	....	93	96	98
	Garden bean	95	89	98	92	79	....	93	89	78	90	60	43	37
	Lettuce	92	95	89	89	87	92	89	....	85	75	87	79	62
68° F. 60 percent relative humidity	Soybean	97	86	79	80	58	44	44	48	29	2	0		
	Rice	92	83	82	73	67	73	75	64	58	31	10	0	
	Alfalfa[2]	87	96	93	99	99	98	96	92	96	75	83	91	78
	Garden bean	95	95	89	96	94	84	94	87	89	90	84	66	71
	Lettuce	92	97	95	92	94	90	90	70	79	49	11	0	
68° F. airtight	Soybean	97	70	55	27	2	1	0						
	Rice	92	73	62	16	24	11	0						
	Alfalfa[2]	87	91	91	88	92	90	86	85	71	62	57	61	65
	Garden bean	95	95	98	91	86	75	86	83	43	4	7	0	
	Lettuce	92	97	97	....	76	65	14	0					
68° F. open	Soybean	97	53	60	53	48	48	48	50	51	7	4	0	
	Rice	92	83	78	74	82	76	67	58	54	43	10	2	4
	Alfalfa[2]	87	94	96	99	97	98	99	99	99	....	100	97	96
	Garden bean	95	93	97	93	73	73	82	82	82	88	64	49	42
	Lettuce	92	92	94	91	93	97	91	93	80	70	89	92	81

[1] Initial germination at time of storage.
[2] Hard seeds cut.

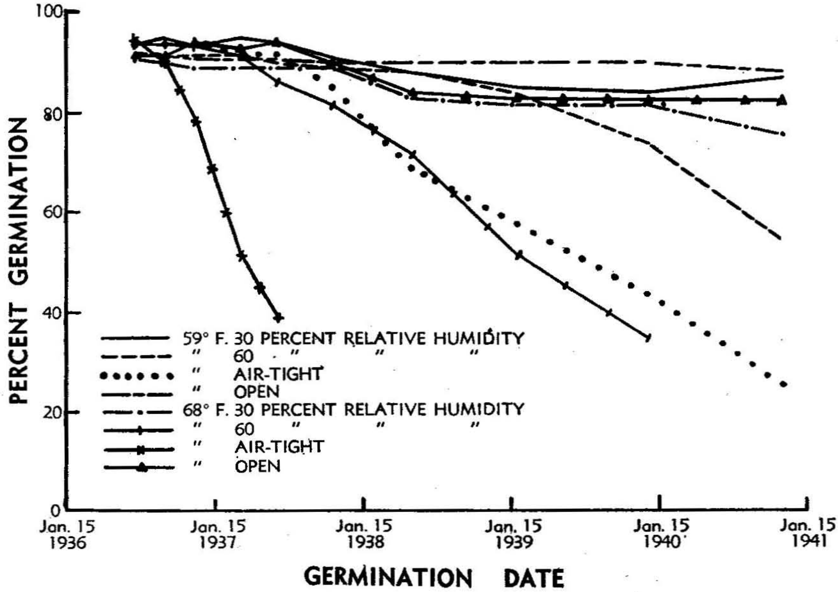

Fig. 4—The effect of low temperature and low relative humidity on viability of stored lettuce seed.

In tables 3, 4, 5, and 6 are recorded the germination results of this experiment obtained over a period of nearly six years of storage. As in the previous experiment, the response of the various seeds stored in different storage conditions, though differing in details, shows similar general trends.

To illustrate the germination behavior of the seeds stored in this experiment, the germination curves of lettuce and soybean seeds were constructed, using points derived from "running averages" of the data in tables 3, 4, 5, and 6. The curves for lettuce are presented in figures 3 and 4; those for soybean are shown in figures 5 and 6.

Germination curves in figures 3, 4, 5, and 6 show that lettuce seed is more tolerant than soybean seed to the various storage media. The lettuce seed maintained its germination in all storage conditions except in the 60-percent humidity and in airtight storage at temperatures of 59° and 68° F. (figs. 3 and 4). In the case of soybean seed, there was a gradual drop in germination as the storage period lengthened, regardless of the storage condition (figs. 5 and 6).

For the storage of lettuce and soybean seeds, temperatures of 45° and 50° F. are in general superior to temperatures of 59° and 68° F. The two lowest temperatures are about equally effective in retaining the viability of the seeds regardless of the humidity conditions employed.

At storage temperatures of 59° and 68° F., the higher relative humidity of 60 percent is less effective than the lower humidity of 30 percent in preserv-

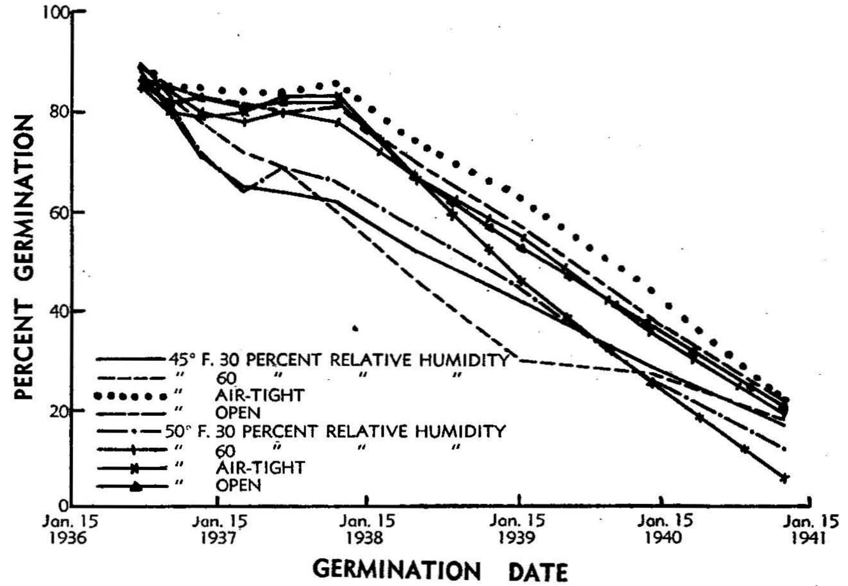

Fig. 5—The effect of low temperature and low relative humidity on viability of stored soybean seed.

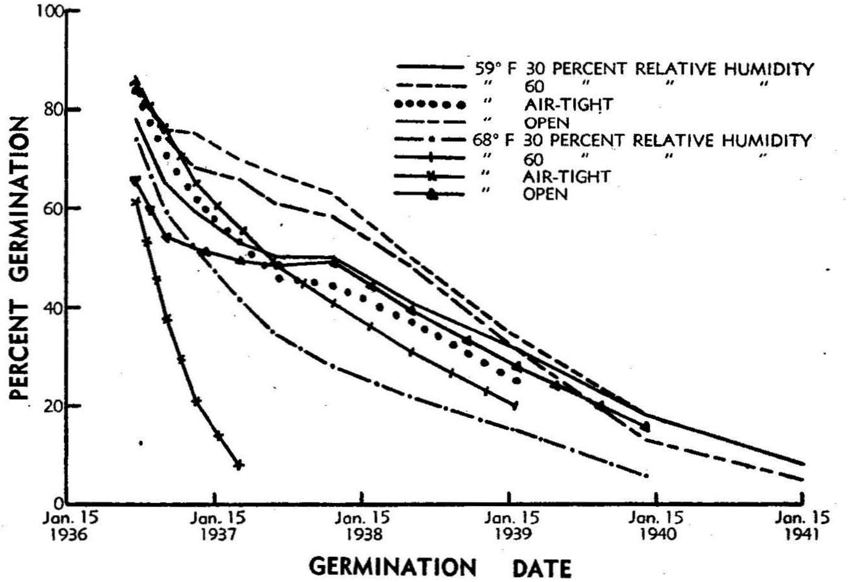

Fig. 6—The effect of low temperature and low relative humidity on viability of stored soybean seed.

ing the viability of lettuce seed according to figure 4. At these temperatures, early in the storage period, the higher humidity seemed to be a better storage medium than the lower humidity for the soybean seed, but toward the latter part of the period, the seeds in the two humidity chambers lost their viability at about the same time (tables 5 and 6; fig. 6).

As in the previous experiment, airtight storage is not superior to ordinary storage even at temperatures below room temperature. At storage temperatures of 45° and 50° F., airtight storage is not so detrimental, but at temperatures of 59° and 68° F., it is definitely detrimental to the maintenance of viability of lettuce and soybean seeds (figs. 3, 4, 5, and 6).

Of particular interest and importance is the fact that even without humidity control, the lettuce and soybean seeds stored open at the low temperatures used in this experiment maintained their germinative power very well—just as well as the same seeds stored at the low humidity conditions. In some cases, open storage was somewhat superior to low humidity storage.

If germination curves are constructed for the other seeds of this experiment, information similar to that obtained from the germination curves of lettuce and soybean will in general be obtained.

DISCUSSION

From the experimental results presented in this bulletin, it is readily seen that temperature and relative humidity of the storage medium play important roles in preserving the vitality of seeds. For long-time storage at room temperature, low relative humidities of 15, 30, and 45 percent provide, in general, excellent storage atmospheres (figs. 1 and 2). At room temperature (64 to 73 percent relative humidity), in which the moisture content of the seed is fairly high, there occurs a rather rapid reduction in germination in storage. A still more rapid reduction in germination occurs under storage at humidities of 75 and 90 percent. Moisture content of the seeds in the higher humidities is higher than that of the seeds in the lower humidities. Thus there appears to be an inverse relationship between the moisture content and the viability of seeds.

The injurious effect on the maintenance of viability of seeds stored in airtight containers is probably associated with the comparatively high moisture content of the stored seeds, a condition which occurs as a result of the high humidity of the air. The slightly lower viability of the seeds stored in airtight containers as compared to those stored in open containers may have been a result of lack of aeration in the storage chamber. Barton (2) found that if carrot, lettuce, onion, and pepper seeds were stored in sealed containers at room temperature without drying with some drying agent, they were injured. Swanson (19) stored wheat of 11-percent-moisture content in an airtight bin for 11 years without losing its vitality to any great extent. Duvel (9) states that thoroughly dried seeds can be stored successfully in airtight containers regardless of temperature and humidity.

That low temperatures—eight degrees and more below the mean room temperature of approximately 76° F.—are helpful in preserving the viability of stored seeds is shown in figures 3, 4, 5, and 6. Soybeans and peanuts have been stored by Spencer (16) under cool storage conditions without loss of viability. The optimum storage condition for the thoroughly desiccated seed of elm was found to be one with a very low temperature of 32° F. (17).

Boswell, *et al* (3), storing some vegetable seeds for a comparatively short period (14 months) at two different temperatures with three different relative humidities, determined that to maintain longevity these seeds should in general be stored in a condition in which either the temperature or the humidity is kept low. Similar results were obtained in the present experiments reported here where seeds were stored for much longer periods under more varying temperature and humidity conditions. If the relative humidity is kept far below that of the normal air, longevity is maintained for an extended period even at room temperature, a temperature which otherwise is too high for maintenance of viability (figs. 1 and 2). Duvel (9) states that air-dried seeds can be stored well in open containers if the atmospheric humidity is low, regardless of temperature conditions (not higher than 98.6° F.), but such a dry atmosphere does not prevail locally. If the temperature is kept far below prevailing room temperature, longevity of the stored seeds is maintained even without humidity control (figs. 3, 4, 5, and 6).

According to Crocker (5), factors affecting the keeping quality of seeds are moisture content, temperature, and oxygen. As regards the seeds studied here, if either the temperature or the humidity (which determines the moisture content of the seeds) is kept far below that prevailing in the normal atmosphere, viability is maintained, and if the seeds are not hindered in their normal gas exchange at low temperature, viability is maintained equally well. Longevity is presumably maintained under conditions which produce the minimum of respiratory activity, and probably under the optimum storage conditions, the respiratory activity of the seeds is at its minimum.

SUMMARY AND RECOMMENDATIONS

The effects of temperature and relative humidity on longevity of stored seeds of garden bean, corn, soybean, alfalfa, rice, lettuce, and *Pennisetum ciliare* were studied.

After approximately 6 years of storage, it was found that:

1. Seeds of different species, although showing similar trends, react somewhat differently toward different storage conditions.

2. In general, longevity is well maintained at relative humidities of at least 20 percent below that of the normal air (64 to 73 percent) even at prevailing room temperatures of approximately 71° to 80° F. Relative humidities between 15 and 45 percent provide excellent storage atmospheres.

3. Longevity is maintained equally well at temperatures of at least 25° F. below that of the normal air even without humidity control. Temperatures of 45° to 50° F. are excellent storage temperatures.

4. The most ideal storage condition is one in which both the relative humidity and the temperature are kept low.

5. Storage of air-dried seeds in airtight containers under the high humidity conditions generally prevalent in Honolulu is detrimental to viability at all temperatures.

6. Maintenance of viability is influenced by the moisture content of the seed, which is in turn determined by the humidity of the storage medium.

In the present emergency the need of increased local production of crops has accelerated seed importation in large quantities from mainland United States and has also accelerated local seed production. Some means to prolong the life of the valuable seeds must be employed.

Since the prevailing temperature and humidity of the air for the Hawaiian Islands are similar to those of Honolulu, where the experiments reported in this bulletin were carried out, the following recommendations for storage of seeds will generally apply to all parts of the Territory.

It is recommended that insect-free, well-cured crop seeds in Hawaii be stored either in cold storage or in a very dry atmosphere at room temperature. A cold storage room is an excellent place to store large quantities of bagged seeds. The cold storage temperature should preferably be not higher than 45° to 50° F. In cold storage, the drip from melting ice should not be allowed to come in contact with the seeds. Seeds should be placed in the driest part of the cold storage room. The driest part of the family refrigerator is an ideal place to store small quantities of seed.

A very dry atmosphere can be obtained by placing some inexpensive but efficient drying agent like calcium chloride or quicklime (commercial grades) at the bottom of an airtight container in such a manner that there will be no contact with the seeds. After the drying agent has absorbed appreciable quantities of moisture, it can either be replaced, or dehydrated in a drying oven and used again. Although sulphuric acid may be used as the drying agent, its use is not recommended, since it is expensive and difficult to handle. Wherever feasible, seeds should be stored in a dry atmosphere in cold storage, since this is the optimum condition of storage for prolonging the vitality of seeds in Hawaii.

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